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"I Know She Invented Fire, but What Has She Done Recently?" or "I Have Come to Praise Ch., not Bury Her!" or 'On the Second Renaissance of Charm Physics' [1]

I.I. Bigi

Department of Physics, University of Notre Dame du Lac
Notre Dame, IN 46556, USA
email: ibigi@nd.edu

Abstract

D^0 oscillations, for which the B factories have found strong evidence, provide a new stage for our search for New Physics in heavy flavour dynamics. While the theoretical verdict on the observed values of x_D and y_D is ambiguous – they could be fully generated by SM dynamics, yet could contain also a sizable contribution from New Physics – such oscillations can enhance the observability of **CP** violation driven by New Physics. After emphasizing the unique role of charm among up-type quarks, I sketch the **CP** phenomenology for partial widths and final state distributions.

Contents

[1]Lecture given at "2nd Workshop on Theory, Phenomenology and Experiments in Heavy Flavour Physics', June 16 - 18, 2008, Capri, Italy

While the first title reflects the spontaneous reaction of a large part of the HEP community, when they hear about charm physics, the second one conveys the message I want to communicate to you, which is condensed into a more conventional form in the third title. The formulation ”Second Renaissance” makes reference to the ”First Renaissance” discussed this morning, which was prompted by the surprises in the spectroscopy of hadrons with open and hidden charm.

Yet first I want to remark on the ‘genius loci’ of Capri that might not be well known to non-Italians. The most venerated oracle in ancient Italy was that of Cumae near Naples with the ‘ageless’ Cumaean Sybil (or prophetess) presiding over it as priestess. A portrait by is shown in Fig.1 This allows me to address two points relevant for our meeting:

Figure 1: Painting of the Cumean Sybil by Andrea del Castagno

(i) Giulia thus stands in a long tradition of female bosses in this part of the world. Keep that in mind when even considering disagreeing with her.

(ii) There is an intriguing legend about the Cumaean Sybil. She had offered nine books with all her prophecies to the last Roman king Tarquinius Superbus for sale. Considering the asking price to stiff, he declined. She then threw three of the books into a fire to burn them and asked the same price for the remaining six books. He still refused, whereupon she burnt three more books. Then he relented and bought the left over three books for the original asking price.The experimentalists among you will recognize that Tarquinius Superbus acted like the typical funding agency that asks for 'de-scoping' your project only to end up paying the same price for less. The theorists will claim that if we had nine flavours to study, we would already have figured out the dynamics underlying the flavour enigma [2].

Back to the main subject. While the study of strange dynamics was instrumental for the creation of the Standard Model (SM) and that of charm transitions central for it being accepted, the analysis of B decays almost completed its validation through the establishment of CKM dynamics as the dominant source of the observed **CP** violation; 'almost', since the Higgs boson has not been observed yet. Now the race is on to see which of these areas together with top quark decays will reveal an incompleteness of the SM in flavour dynamics. If the evidence for D^0 oscillations with x_D, $y_D \sim 0.005 - 0.01$ gets confirmed, then the detailed probe of **CP** symmetry in charm decays is just behind the race leader, namely the even more detailed study of B decays.

The signal for D^0 oscillations marks a *tactical* draw: while the values measured for x_D and y_D might be generated by SM forces alone, they could contain relatively large contributions from New Physics (NP). Yet a *strategic* victory is in sight: studies of **CP** symmetry in D decays will decide the issue possibly paving the way for a *new* SM to emerge. I would like to draw a historical analogy based on my personal experience. Sanda and myself had been talking about large **CP** asymmetries in B decays [1] without much resonance – till $B_d - \bar{B}_d$ oscillations were resolved by the ARGUS collaboration in 1987 [2], i.e. twenty-one years ago. Yet quantitatively we have a 'centi-ARGUS' scenario with the oscillation parameter x_D being about two orders of magnitude smaller than x_B. **CP** asymmetries in D decays will be smaller than what was found in B decays. However the 'background' from SM dynamics is even tinier. I would also count on our experimentalists having become more experienced and thus being able to extract smaller signals.

The outline of the talk is as follows: after a Prologue on the unique place of charm studies in searches for New Physics I review our inconclusive interpretation of the data on D^0 oscillations before my central message – the need for a comprehensive search for **CP** violation in charm decays. After an Outlook I conclude with an Epilogue on the shift between 'Capri I' and 'Capri II'.

1 Prologue: On Charm's Unique Place

NP in general induces flavour changing neutral currents (FCNC). The SM and many viable NP models had to be carefully crafted to suppress FCNC below acceptable levels.

[2] As pointed out by P. Colangelo in his talk there is a difference between 'enigma' and 'puzzle'.

FCNC could be much stronger for *up*-type than for down-type quarks – quite unlike the situation within the SM. This actually happens in some models which 'brush the dirt' of FCNC in the down-type sector under the 'rug' of the up-type sector.

With the SM 'background' smaller for FCNC of up-type quarks, we can hope for cleaner though not necessarily larger NP signals there:

$$\left.\frac{\text{NP signal}}{\text{SM 'noise'}}\right|_{\text{up-type}} > \left.\frac{\text{NP signal}}{\text{SM 'noise'}}\right|_{\text{down-type}} \tag{1}$$

Among up-type quarks it is only charm that allows the full range of probes for FCNC and New Physics in general: (i) Top quarks decay *before* they can hadronize [3]. Without top *hadrons* $T^0 - \bar{T}^0$ oscillations cannot occur. This limits our options to search for **CP** asymmetries, since one cannot call on oscillations to provide the required second amplitude. (i) Hadrons built with u and $\bar{u}$ quarks like π^0 and η are their own antiparticle; thus there can be no $\pi^0 - \pi^0$ etc. oscillations as a matter of principle. Furthermore they possess so few decay channels that **CPT** invariance basically rules out **CP** asymmetries in their decays.

I will show that only recently have experiments reached a range of sensitivity, where one can realistically expect **CP** violation to show up in charm transitions. My basic contention is as follows: *Charm transitions are a unique portal for obtaining novel access to flavour dynamics with the experimental situation being a priori favourable apart from the absence of Cabibbo suppression.*

2 On the Interpretation of D^0 Oscillations

In the limit of **CP** invariance oscillations are described by the normalized mass and width splittings: $x_D \equiv \frac{\Delta M_D}{\Gamma_D}$, $y_D \equiv \frac{\Delta\Gamma_D}{2\Gamma_D}$. While the SM predicts similar numbers for x_D and y_D with the data showing the same trend, we should note that ΔM_D and $\Delta\Gamma_D$ reflect different dynamics: ΔM_D is produced by *off*-shell transitions making it naturally sensitive to NP unlike $\Delta\Gamma_D$, which is generated by *on*-shell modes. A central theoretical issue is to which degree quark-hadron duality can be invoked, in particular for $\Delta\Gamma_D$, which involves less averaging or 'smearing' than ΔM_D; or in more general terms: how sensitive is $\Delta\Gamma_D$ to the proximity of several hadronic thresholds [4].

2.1 Theoretical Estimates and Data

Within the SM two reasons combine to make x_D and y_D small in contrast to the situation for $B^0 - \bar{B}^0$ and $K^0 - \bar{K}^0$ oscillations, namely the double Cabibbo suppression of the amplitude for $D^0 \leftrightarrow \bar{D}^0$ coupled with the GIM suppression being controlled by the breaking of $SU(3)_{fl}$. A rather conservative bound reads [4]:

$$x_D,\, y_D \sim \text{SU(3)}_{\text{fl}}\,\text{break.} \times 2\sin^2\theta_C < \text{few} \times 0.01 \tag{2}$$

The description of $SU(3)_{fl}$ breaking becomes a central issue. While $x_D \ll y_D$ would be unnatural, it cannot be ruled out. The history of the predictions on D^0 oscillations does not provide a tale of consistently sound judgment by theorists, when they predicted $x_D \leq$ few $\times 10^{-4}$. Yet scientific progress is not made by majority vote, although that codifies it in the end. It should be noted that words of caution had been sounded; e.g. in 1997 [5]: *"... It is often stated that the SM predicts ... $x_D, y_D \leq 3 \cdot 10^{-4}$. I myself am somewhat flabbergasted by the boldness of such predictions ... I cannot see how anyone can make such a claim with the required confidence ... "* Warnings similar in substance – albeit more diplomatic in tone – had been sounded by Wolfenstein and Donoghue.

In estimating the strength of $\mathcal{L}(\Delta C = 2)$ authors had typically relied on evaluating quark box diagrams that had been faithful guides for $\mathcal{L}(\Delta S = 2)$ and $\mathcal{L}(\Delta B = 2)$, while overlooking the fact that the resulting GIM suppression of $(m_s/m_c)^4$ is un-typically severe. The often heard statement that oscillations of mesons built from *up* type quarks teach us about *down* type quark dynamics – which is inspired by looking at quark box diagrams with charged currents – is thus misleading. The correct statement is that those oscillations tell us about the FCNC of *up* type quarks.

Two complementary approaches to evaluating ΔM_D and $\Delta\Gamma_D$ in the SM represent the state of the art. They can be referred to as 'fully inclusive' and 'summing over exclusive channels'.

In the 'inclusive' approach one constructs an operator product expansion (OPE) in terms of operators constructed from quark and gluon fields and takes their expectation value. There is one new element relative to what has been done with great success in B decays: One has to include contributions from quark condensates – i.e., vacuum expectation values $\langle 0|\bar{q}q|0\rangle$ – in addition to D^0 expectation values, since the quark box contributions, which represent the partonic term, are so severely suppressed here, as mentioned above. Thus one has to deal with three parameters with mass dimension, namely m_c, m_s and the condensate scale μ_{had}. Since μ_{had} and m_c are comparable in size, the resulting OPE is not a very robust one, at least numerically. One finds that the largest contribution is $\mathcal{O}(m_s^2\mu_{had}^4/m_c^6)$ rather than the formally leading quark box term $\mathcal{O}(m_s^4/m_c^4)$ [4]:

$$x_D(SM)|_{OPE},\ y_D(SM)|_{OPE} \sim \mathcal{O}(10^{-3}) \tag{3}$$

with a slight preference for $x_D(SM)|_{OPE} < y_D(SM)|_{OPE}$; their relative sign is not predicted. On the other hand one infers

$$\mathrm{arg} M_{12}^D(SM)/\Gamma_{12}^D(SM)|_{OPE} \sim \lambda^4\eta \leq 10^{-3} \tag{4}$$

As stated before, violations of quark-hadron duality due to the relative proximity of several relevant production thresholds could enhance in particular y_D over this estimate. In any case it appears quite unlikely that the theoretical uncertainty of this estimate can be reduced.

The other approach [6] operates on the purely hadronic rather than quark-gluon level. 2-, 3- and 4-body modes are considered with $SU(3)_{fl}$ breaking in the decay rates identified with that due to their phase space alone. Summing over these groups of channels yields

an estimate for $\Delta\Gamma_D$ and a dispersion relation for ΔM_D:

$$y_D(SM) \sim 0.01 \; , \;\; 0.001 \leq |x_D(SM)| \leq y_D \tag{5}$$

with $y_D(SM)$ and $x_D(SM)$ being of opposite sign; $\arg M_{12}^D/\Gamma_{12}^D$ cannot be predicted this way.

In evaluating the theoretical situation one has to distinguish carefully between two similar sounding questions:

1. What is the most likely SM value for x_D, y_D? My answer is as before: $\mathcal{O}(10^{-3})$.
2. Can one rule out 0.01? There I say 'no'!

In the Spring of 2007 intriguing evidence for D^0 oscillations has been presented by the BaBar [7] and Belle [8] collaborations. Averaging over them HFAG [9] finds $(x_D, y_D) \neq (0, 0)$ with more than 6 sigma significance; more specifically:

$$x_D = (0.89^{+0.26}_{-0.27})\% \; , \;\; y_D = (0.75^{+0.17}_{-0.18})\% \tag{6}$$

I fervently hope that more precise measurements will confirm these oscillation signals with x_D and y_D in the range 0.5 - 1%. Establishing D^0 oscillations would provide a novel insight into flavour dynamics. After having discovered oscillations in *all three* mesons built from *down*-type quarks – K^0, B_d and B_s – it would be the first observation of oscillations with *up*-type quarks; it would also remain the only one (at least for three-family scenarios), as explained above.

2.2 Interpretation?

It would have been conceivable to measure $y_D \ll x_D \sim$ few $\times$ 0.01 thus establishing the intervention of NP. This has not happened: we are in a grey zone, where the observed strengths of both y_D and x_D might be produced by SM forces alone – or could contain significant contributions from NP. Even in the former case one should probe these oscillations as accurately as possible first establishing $[x_D, y_D] \neq [0, 0]$ and then determining x_D vs. y_D. Analogous to the situation with ϵ'/ϵ_K one has to aim at measuring them irrespective of limitations in our theoretical tools.

A future theoretical breakthrough might allow us to predict $x_D|_{SM}$ and $y_D|_{SM}$ more accurately and thus resolve the ambiguity in our interpretation, but I would not count on it. Rather than wait for that to happen the community should become active in the catholic tradition of 'active repentance' and search for **CP** violation in D decays. Even if NP is not the main engine for ΔM_D, it could well be the leading source of **CP** violation in $\mathcal{L}(\Delta C = 2)$. There is an analogy to the case of B_s oscillations. $\Delta M(B_s)$ has been observed to be consistent with the SM prediction within mainly theoretical uncertainties; yet since those are still sizable, we cannot rule out that NP impacts B_s oscillations significantly. This issue, which is unlikely to be resolved soon theoretically, can be decided experimentally by searching for a time dependent **CP** violation in $B_s(t) \to \psi\phi$. For within

the SM one predicts [1] a very small asymmetry not exceeding 4% in this transition since on the leading CKM level quarks of only the second and third family contribute. Yet in general one can expect NP contributions to B_s oscillations to exhibit a weak phase that is not particularly suppressed. Even if NP affects $\Delta M(B_s)$ only moderately, it could greatly enhance the time dependent **CP** asymmetry in $B_s(t) \to \psi\phi$. This analogy is of course qualitative rather than quantitative with D^0 oscillations being quite slow.

3 CP Violation – the Decisive Stage

3.1 On NP Effects

Probing **CP** invariance for manifestations of NP is not a 'wild goose chase'. For we know that CKM dynamics is completely irrelevant for baryogenesis; i.e., we need **CP** violating NP to understand the Universe's observed baryon number as a *dynamically generated* quantity rather than an arbitrary initial value.

There is no need to construct crazy NP scenarios for charm transitions – being innovative will do. At present we have the "usual list of suspects" [10]: *Non*-minimal SUSY with(out) R parity (up-squarks might be less degenerate than down-squarks), Higgs dynamics with*out* natural flavour conservation, Little Higgs models, extra dimensions etc. I do not know of persuasive NP scenarios that would affect D decays, but not B and K decays. Yet their manifestations might stand out more clearly in D where there is little SM 'background'. It behooves us to show some humility in judging whether a scenario is persuasive. For while we know so much about flavour dynamics, we understand very little. Probing **CP** symmetry in charm transitions is certainly of the 'hypothesis-generating' rather than 'hypothesis-probing' variety.

Charm decays offer several *pragmatic* advantages in such searches:
(i) While we do not know how to reliably compute the strong phase shifts required for direct **CP** violation to emerge in partial widths, we can expect them to be large, since charm decays proceed in an environment populated by many resonances. *Hadronization thus enhances the observability of* **CP** *violation*; it 'only' causes a problem when we attempt to interpret the findings in terms of microscopic NP parameters.
(ii) The branching ratios into relevant modes are relatively large.
(iii) Asymmetries being linear in NP amplitudes enjoy enhanced sensitivity to the latter.
(iv) The soft pions from $D^* \to D\pi$ provide a powerful tagging tool.
(v) Many D decays lead to three or more pseudoscalar mesons with various resonant structures. This complexity allows **CP** asymmetries to surface in final state distributions rather than merely in partial widths, and significantly larger asymmetries might arise in the former than the latter.
(vi) The 'background' from known physics is small. According to the SM there is a three-level Cabibbo hierarchy with the rates of Cabibbo allowed, once and doubly Cabibbo suppressed modes scaling roughly like 1 : 1/20 : 1/400. The SM makes non-trivial predictions for each of these Cabibbo levels. *Without* oscillations direct **CP** violation can arise only in *singly* Cabibbo suppressed transitions, where it is driven by the highly diluted

phase $\sim \lambda^4\eta$ of $V(cs)$. One expects asymmetries to reach no better than the 0.1 % level; significantly larger values would signal NP. *Almost any* asymmetry in Cabibbo *allowed* or *doubly suppressed* channels requires the intervention of New Physics, since – in the absence of oscillations – there is only one weak amplitude. The exception are channels containing a K_S (or K_L) in the final state like $D \to K_S\pi$. There are two sources for a **CP** asymmetry from known dynamics: (i) Two transition amplitudes are actually involved, a Cabibbo favoured and a doubly suppressed one, $D \to \bar K^0\pi$ and $D \to K^0\pi$, respectively. Their relative *weak* CKM phase is given by $\eta A^2\lambda^6 \sim$ few $\cdot 10^{-5}$, which seems to be well beyond observability. (ii) While one has $|T(D \to \bar K^0\pi)| = |T(\bar D \to K^0\pi)|$, the **CP** impurity $|p| \neq |q|$ in the K_S wave function introduces a difference between $D^{0,+} \to K_S\pi^{0,+}$ and $\bar D^{0,-}\bar K_S\pi^{0,-}$ of $\frac{|q|^2-|p|^2}{|q|^2+|p|^2} = (3.32 \pm 0.06)\cdot 10^{-3}$ [4].

With oscillations on an observable level – and it seems x_D, $y_D \sim 0.005 - 0.01$ satisfy this requirement – the possibilities for **CP** asymmetries proliferate. Those will allow us to decide whether NP is involved.

3.2 Oscillations as New CP Portal

In the presence of $D^0 - \bar D^0$ oscillations *time-dependent* **CP** asymmetries can arise in D^0 decays on the Cabibbo allowed ($D^0 \to K_S\phi$ [3], $K_S\rho^0$, $K_S\pi^0$), once forbidden ($D^0 \to K^+K^-$, $\pi^+\pi^-$) and doubly forbidden ($D^0 \to K^+\pi^-$) levels. Let me list just two prominent examples from the last two categories. Since y_D, $x_D \ll 1$, it suffices to give the decay rate evolution to first order in those quantities only (the general expressions can be found in Ref.[4]).

$$\begin{aligned}\Gamma(D^0(t) \to K^+K^-) &\propto e^{-\Gamma_1 t}|T(D^0 \to K^+K^-)|^2 \times \\ &\left[1 + y_D\frac{t}{\tau_D}(1 - \mathrm{Re}\frac{q}{p}\bar\rho_{K^+K^-}) - x_D\frac{t}{\tau_D}\mathrm{Im}\frac{q}{p}\bar\rho_{K^+K^-}\right] \qquad (7)\\ \Gamma(\bar D^0(t) \to K^+K^-) &\propto e^{-\Gamma_1 t}|T(\bar D^0 \to K^+K^-)|^2 \times \\ &\left[1 + y_D\frac{t}{\tau_D}(1 - \mathrm{Re}\frac{p}{q}\frac{1}{\rho_{K^+K^-}}) - x_D\frac{t}{\tau_D}\mathrm{Im}\frac{p}{q}\frac{1}{\rho_{K^+K^-}}\right] \qquad (8)\end{aligned}$$

The usual three types of **CP** violation can arise, namely the direct and indirect types – $|\bar\rho_{K^+K^-}| \neq 0$ and $|q| \neq |p|$, respectively – as well as the one involving the interference between the oscillation and direct decay amplitudes – $\mathrm{Im}\frac{q}{p}\bar\rho_{K^+K^-} \neq 0$ leading also to $\mathrm{Re}\frac{q}{p}\bar\rho_{K^+K^-} \neq 1$. Assuming for simplicity [4] $|T(D^0 \to K^+K^-)| = |T(\bar D^0 \to K^+K^-)|$ and $|q/p| = 1 - \epsilon_D$ with $|\epsilon_D| \ll 1$ one has $(q/p)\bar\rho_{K^+K^-} = (1-\epsilon_D)e^{i\phi_{K\bar K}}$ and thus

$$\frac{\Gamma(\bar D^0(t) \to K^+K^-) - \Gamma(D^0(t) \to K^+K^-)}{\Gamma(\bar D^0(t) \to K^+K^-) + \Gamma(D^0(t) \to K^+K^-)} \simeq x_D\frac{t}{\tau_D}\sin\phi_{K\bar K} - y_D\frac{t}{\tau_D}\epsilon_D\cos\phi_{K\bar K}\ . \qquad (9)$$

[3] Since the final state $K_S\phi$ is mainly given by a single isospin amplitude, the strong phase basically drops out from $T(\bar D^0 \to K_S\phi)/T(D^0 \to K_S\phi)$; i.e., the **CP** asymmetry measures the NP weak phase.

[4] CKM dynamics is expected to induce an asymmetry not exceeding 0.1%.

BELLE has found [8] for such an asymmetry integrated over time:

$$A_\Gamma = (0.01 \pm 0.30 \pm 0.15)\% \tag{10}$$

While there is no evidence for **CP** violation in the transition, one should also note that the asymmetry is bounded by x_D, y_D. For x_D, $y_D \leq 0.01$, as indicated by the data, A_Γ could hardly exceed the 1% range; i.e., there is not much of a bound on ϕ_D or ϵ_D so far. Yet any improvement in the experimental sensitivity for $D^0(t) \to K^+K^-$ constrains NP scenarios – or could reveal them [11].

Another promising channel for probing **CP** symmetry is $D^0(t) \to K^+\pi^-$: since it is doubly Cabibbo suppressed, it should a priori exhibit a higher sensitivity to a New Physics amplitude. Furthermore it cannot exhibit direct **CP** violation in the SM. With

$$\frac{q}{p}\frac{T(D^0 \to K^+\pi^-)}{T(D^0 \to K^-\pi^+)}\left[\frac{p}{q}\frac{T(\bar{D}^0 \to K^-\pi^+)}{T(\bar{D}^0 \to K^+\pi^-)}\right] \equiv -\frac{1}{\mathrm{tg}^2\theta_C}(1-[+]\epsilon_D)|\hat{\rho}_{K\pi}|e^{-i(\delta-[+]\phi_{K\pi})} \tag{11}$$

one expresses an asymmetry as follows:

$$\frac{\Gamma(\bar{D}^0(t) \to K^-\pi^+) - \Gamma(D^0(t) \to K^+\pi^-)}{\Gamma(\bar{D}^0(t) \to K^-\pi^+) + \Gamma(D^0(t) \to K^+\pi^-)} \simeq$$

$$\left(\frac{t}{\tau_D}\right)|\hat{\rho}_{K\pi}|\left(\frac{y'_D\cos\phi_{K\pi}\epsilon_D - x'_D\sin\phi_{K\pi}}{\mathrm{tg}\theta_C^2}\right) + \left(\frac{t}{\tau_D}\right)^2|\hat{\rho}_{K\pi}|^2\frac{\epsilon_D(x_D^2+y_D^2)}{2\mathrm{tg}\theta_C^4} \tag{12}$$

where I have again assumed for simplicity $|\epsilon_D| \ll 1$ and *no direct* **CP** violation.

BABAR has searched for a time dependent **CP** asymmetry in $D^0 \to K^+\pi^-$ vs. $\bar{D}^0(t) \to K^-\pi^+$, yet so far not found any evidence [7]. Again, with x'_D and y'_D capped by about 1%, no nontrivial bound can be placed on the weak phase $\phi_{K\pi}$. On the other hand any further increase in experimental sensitivity could reveal a signal.

3.3 On CPT Constraints

CPT symmetry provides more constraints than just equality of mass and lifetime of particles and antiparticles. For it tells us that the widths for subclasses of transitions have to be the same. For simplicity consider a toy model where the D meson can decay only into two classes of final states $A = \{a_i, i = 1, ..., n\}$ and $B = \{b_j, j = 1, ..., m\}$ with the strong interactions allowing members of the class A to rescatter into each other and likewise for class B, but *no* rescattering possible *between* classes A and B. Then **CPT** symmetry tells us partial width asymmetries *summed* over class A already have to vanish and likewise for class B. This **CPT** 'filter' can hardly be of any practical use for B decays with their multitude of channels, yet for D decays it might provide nontrivial validation checks. Details can be found in Ref.[12].

3.4 Final State Distributions

Decays to final states of *more than* two pseudoscalar or one pseudoscalar and one vector meson contain more dynamical information than given by their widths; their distributions as described by Dalitz plots or **T**-*odd* moments can exhibit **CP** asymmetries that can be considerably larger than those for the width. All **CP** asymmetries observed so far in K_L and B_d decays except one concern partial widths, i.e. $\Gamma(P \to f) \neq \Gamma(\bar{P} \to \bar{f})$. The one notable exception can teach us important lessons for future searches both in charm and B decays, namely the **T** odd moment found in $K_L \to \pi^+\pi^-e^+e^-$. Denoting by ϕ the angle between the $\pi^+\pi^-$ and e^+e^- planes one has

$$\frac{d\Gamma}{d\phi}(K_L \to \pi^+\pi^-e^+e^-) = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi \tag{13}$$

Comparing the ϕ distribution integrated over two quadrants one obtains a **T** *odd* moment:

$$\langle A \rangle = \frac{\int_0^{\pi/2} d\phi \frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi \frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)} \tag{14}$$

$\langle A \rangle$ is measured to be 0.137 ± 0.015 [13] in full agreement with the prediction of 0.143 ± 0.013 [14]. Most remarkably this large asymmetry is generated by the tiny **CP** impurity parameter $\eta_{+-} \simeq 0.0024$; i.e., the impact of the latter is magnified by a factor of almost a hundred – for the price of a tiny branching ratio of about $3 \cdot 10^{-7}$!

Likewise one might find larger **CP** asymmetries in final state distributions of three-, four-body etc. D decays like $D \to 3\pi$, $K\bar{K}\pi$, $K\bar{K}\pi\pi$, $K\bar{K}\mu^+\mu^-$. As far as three-body modes are concerned we have a 'catholic' scenario: there is a single canonical path to heaven – the Dalitz plot. Four-body modes on the other hand represent a 'Calvinist scenario': while *a priori* many paths can lead to heaven – generalized Dalitz studies, angular asymmetries in the decay planes as sketched above for $K_L \to \pi^+\pi^-e^+e^-$ etc. – Heaven's blessing will be revealed *a posteriori through success*. A pilot study of $D^0 \to K^+K^-\pi^+\pi^-$ vs. $\bar{D}^0 \to K^+K^-\pi^+\pi^-$ has been undertaken by the FOCUS collaboration [15].

3.5 Semileptonic D^0 Decays

$|q/p| \neq 1$ unambiguously reflects **CP** violation in $\Delta C = 2$ dynamics. It can be probed most directly in semileptonic D^0 decays leading to 'wrong sign' leptons:

$$a_{SL}(D^0) \equiv \frac{\Gamma(D^0(t) \to l^-X) - \Gamma(\bar{D}^0 \to l^+X)}{\Gamma(D^0(t) \to l^-X) + \Gamma(\bar{D}^0 \to l^+X)} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4} \tag{15}$$

The corresponding observable has been studied in semileptonic decays of neutral K and B mesons. With a_{SL} being controlled by $(\Delta\Gamma/\Delta M)\sin\phi_{weak}$, it is predicted to be small in both cases, albeit for different reasons: (i) While $(\Delta\Gamma_K/\Delta M_K) \sim 1$ one has $\sin\phi^K_{weak} \ll 1$ leading to $a^K_{SL} = \delta_l \simeq (3.32 \pm 0.06) \cdot 10^{-3}$ as observed. (ii) For B^0 on the other hand one has $(\Delta\Gamma_B/\Delta M_B) \ll 1$ leading to $a^B_{SL} < 10^{-3}$.

For D^0 both ΔM_D and $\Delta\Gamma_D$ are small, yet $\Delta\Gamma_D/\Delta M_D$ is not: present data indicate it is about unity; a_{SL} is given by the smaller of $\Delta\Gamma_D/\Delta M_D$ or its inverse multiplied by $\sin\phi^D_{weak}$, which might not be that small: i.e., while the rate for 'wrong-sign' leptons is small in semileptonic decays of neutral D mesons, their **CP** asymmetry might not be at all, if New Physics intervenes to generate ϕ^D_{weak}.

3.6 Benchmark Goals

Viable NP scenarios could produce **CP** asymmetries close to the present experimental bounds, but hardly higher. To have a realistic chance to find an effect, one should strive to reach at least

- the $\mathcal{O}(10^{-4})$ [$\mathcal{O}(10^{-3})$] level for time-dependent **CP** asymmetries in $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K_S\rho^0$, $K_S\phi$ [$D^0 \to K^+\pi^-$];
- direct **CP** asymmetries in partial widths down to $\mathcal{O}(10^{-3})$ in $D \to K_S\pi$ and in singly Cabibbo suppressed modes and down to $\mathcal{O}(10^{-2})$ in doubly Cabibbo suppressed modes;
- the $\mathcal{O}(10^{-3})$ level in Dalitz asymmetries and **T** odd moments.

4 Conclusions and Outlook

It is important to firmly establish the existence of D^0 oscillations and determine x_D vs. y_D. My main message is that we must go after **CP** violation in charm transitions in all of its possible manifestations, both time dependent and independent, in partial widths and final state distributions, and on all Cabibbo levels down to the 10^{-3} or even smaller level. The present absence of any **CP** asymmetry is not telling. Comprehensive and detailed **CP** studies of charm decays provide a unique window onto flavour dynamics.

For that purpose we need the statistical muscle of LHCb. Charm studies constitute a worthy challenge to LHCb, for which $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K^+\pi^-$, $K^+K^-\pi^+\pi^-$, $K^+K^-\mu^+\mu^-$ represent good channels. On the theory side we can expect a positive learning curve for theorists, yet should not count on miracles. Therefore we have to go after even more statistics and more channels, including those with (multi)neutrals to validate our future conclusions. This brings me to my second message:

"Ceterum censeo fabricam super saporis esse faciendam!"
"Moreover I advise a super-flavour factory has to be built!"

Such a machine could provide an even more optimal environment, if it could be operated also at charm threshold with decent luminosity.

5 Epilogue: From Capri I to Capri II

While I had failed to attend the first workshop here in Capri, I still used its poster for a talk at DIF06 appropriately (as I thought) modified, see Fig.2. Among other things it led

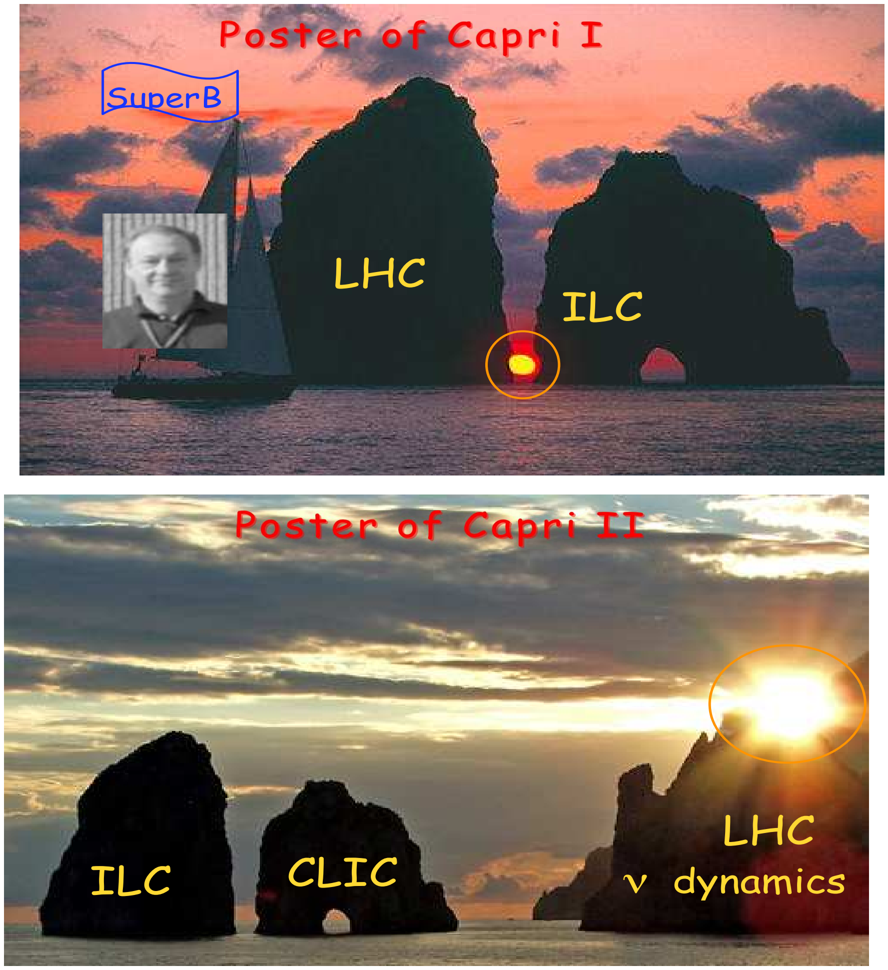

Figure 2: Modified posters of the Capri I (top) and Capri II (bottom) workshops

to a question: Does it show a rising or a setting sun? I was quite intrigued when I saw that the poster for Capri II reflected the changed landscape of HEP in a rather poetic way (being 'subtlety challenged' I have illustrated these changes, see Fig.2); it contains two further messages: (i) The vitality of the light rays indicates it must be a rising sun and (ii) the passage for Super-B has become wider!

A final thought: Models with extra dimensions have several ad-hoc features. But they are sufficiently radical to push our thinking out of its present comfort zone into novel fruitful directions; i.e., they are a most helpful 'imagination stretcher' in the language of L. Sehgal.

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